How FLUXNET data and Models work together to improve knowledge on the Carbon Cycle

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Outline

1. Northern forests, model optimisation using eddy-data
2. Northern forests, model optimisation using eddy and satellite
3. Tropical forests model flux seasonality optimization
4. Calibrating the modelled response of fluxes to climate

1. Northern forests, model optimisation using eddy-data

Objectives

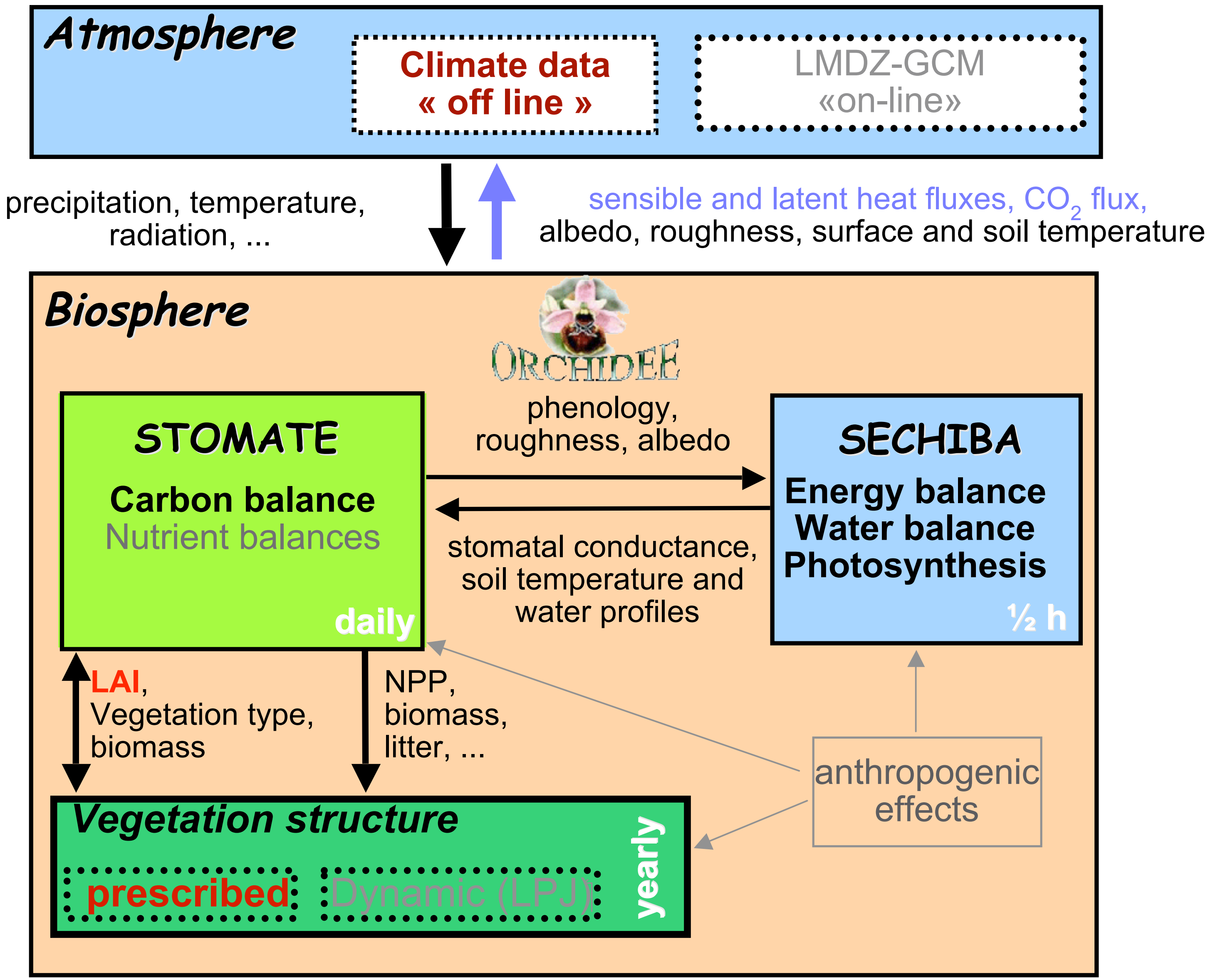
Improve ORCHIDEE vegetation model by parameter optim.

- Variational assimilation scheme
- Data at the site level
    - ✓ **Flux** = NEE, H, and LE, fluxes
    - ✓ **fAPAR** = SPOT (40m / ≈ monthly) and MERIS (1 km / ≈ weekly)

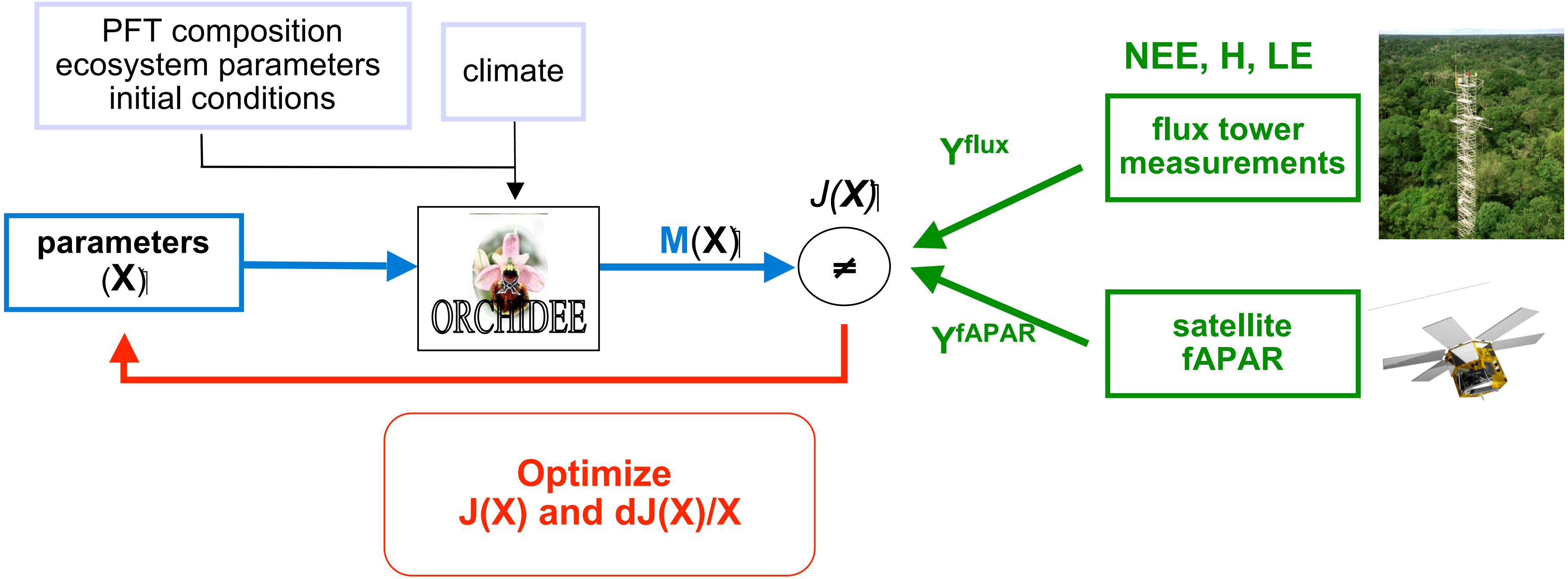
Main question

- What are the parameters constrained by eddy data
- Can we combine flux data and satellite fAPAR at the site level ?
- What do we learn from the optimisation process ?

The guinea pig : the ORCHIDEE vegetation model



Variational assimilation system



Governing processes and parameters to optimize

- Photosynthesis → **Kvmax**, **Gsslope**, **LAIMAX**, SLA, ThetaLeaf
- Autotrophic respiration → frac_resp_growth, respm_T_slope, respm_T_ord
- Heterotrophic respiration → **Q10**, Hc, **Kresph**
- Plant phenology → **Kgdd**, **Tsen**, Leafage
- Energy balance → albedo, capasoil, r_aero

Few technical aspects

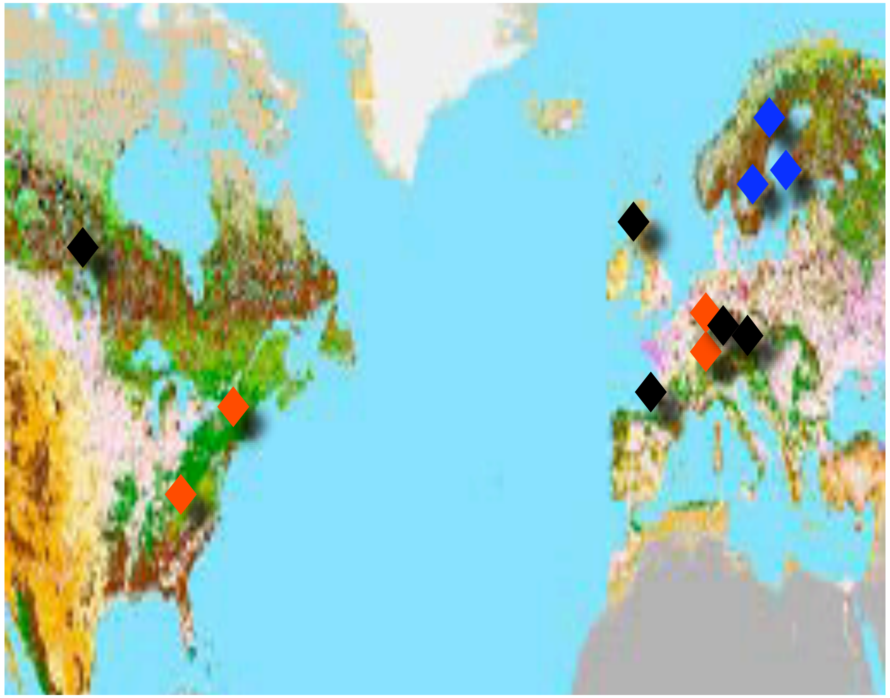
Bayesian cost function separates time scales

$J(\mathbf{X}) = (\mathbf{Y}^{flux}_{daily} - \mathbf{M}(\mathbf{X}))^T \mathbf{R}_{season}^{-1} (\mathbf{Y}^{flux}_{daily} - \mathbf{M}(\mathbf{X}))$	+	daily means
$(\mathbf{Y}^{flux}_{diurnal} - \mathbf{M}(\mathbf{X}))^T \mathbf{R}_{diurnal}^{-1} (\mathbf{Y}^{flux}_{diurnal} - \mathbf{M}(\mathbf{X}))$	+	diurnal cycle
$(\mathbf{Y}^{fAPAR} - \mathbf{M}(\mathbf{X}))^T \mathbf{R}_{fAPAR}^{-1} (\mathbf{Y}^{fAPAR} - \mathbf{M}(\mathbf{X}))$	+	fAPAR
$(\mathbf{X} - \mathbf{X}_0)^T \mathbf{P}^{-1} (\mathbf{X} - \mathbf{X}_0)$		prior parameters

Issues

- **Accurate computing of *J(X)* gradient (finite differences / adjoint)**
- **No account for ½-hourly data/model error correlations ?**
- **Relative weight between NEE, H, LE, R_n flux observations**
- **How to treat thresholds linked to phenology ? (i.e. GDD > GDD_{crit})**

Results at selected Northern forest sites



- Deciduous

Hesse HE (96-99)

Harvard HV (92-96)

Vielsam VI (96-98)

Walker Branch WB (95-98)

- Temperate conifers

Aberfeldy (97-98)

Bray (97-98)

Tharandt (96-00)

WE (96-99)

- Boreal conifers

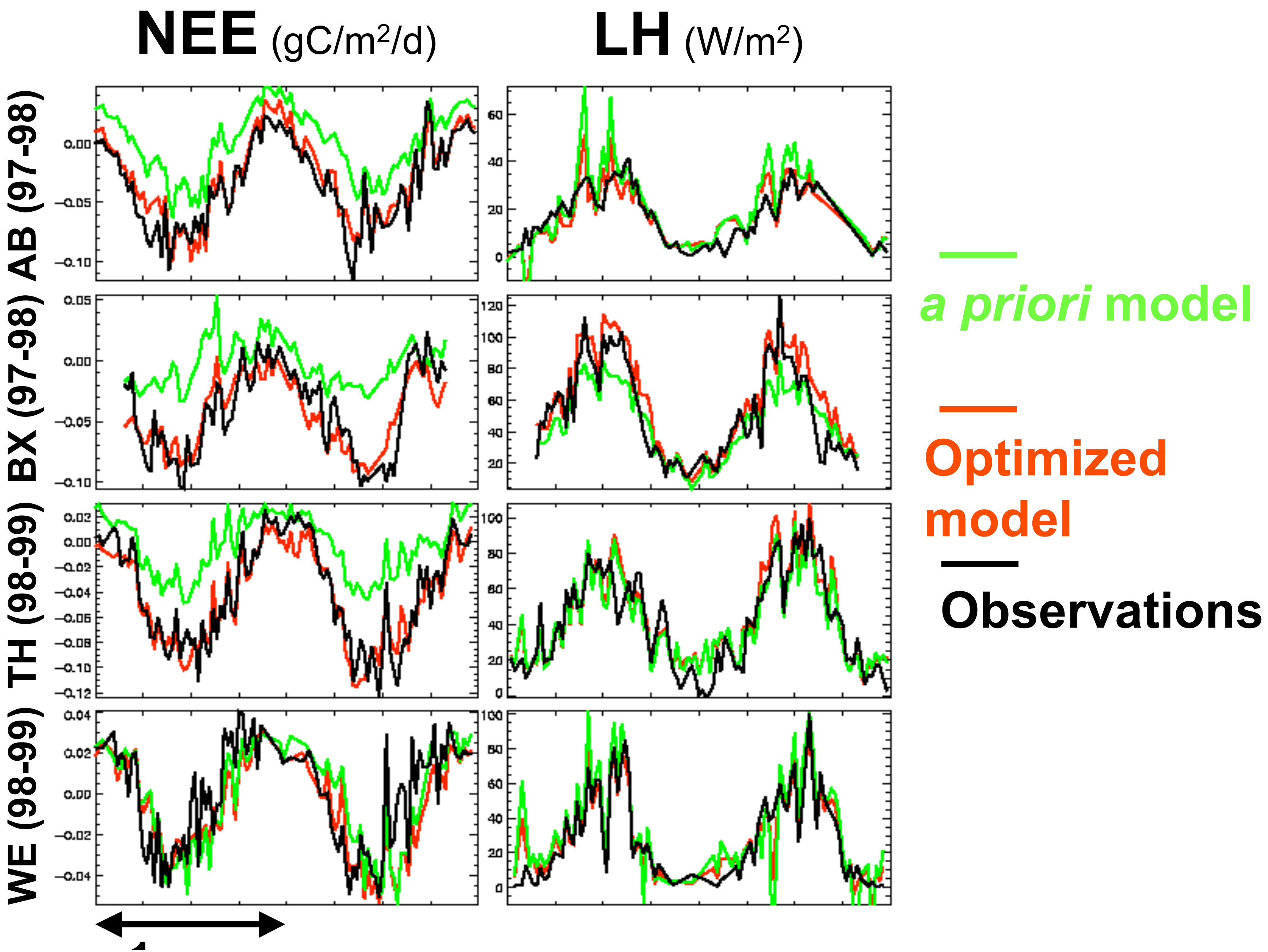
Flakadinnen (96-98)

Hyytyalla (96-00)

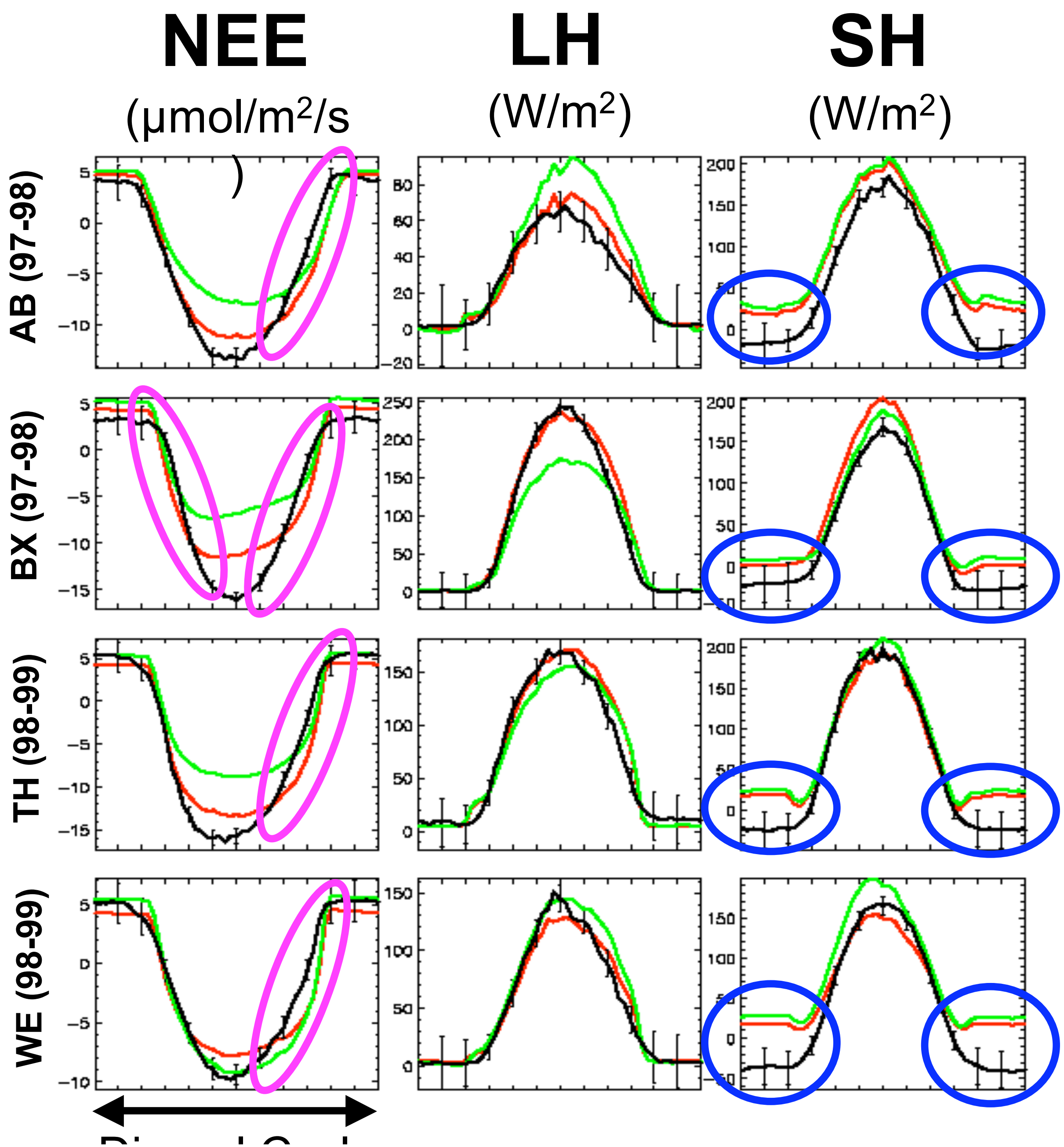
North Boreas (94-98)

Norunda (96-98)

Temperate conifers seasonal cycle



Temperate conifers : diurnal cycle



a priori model

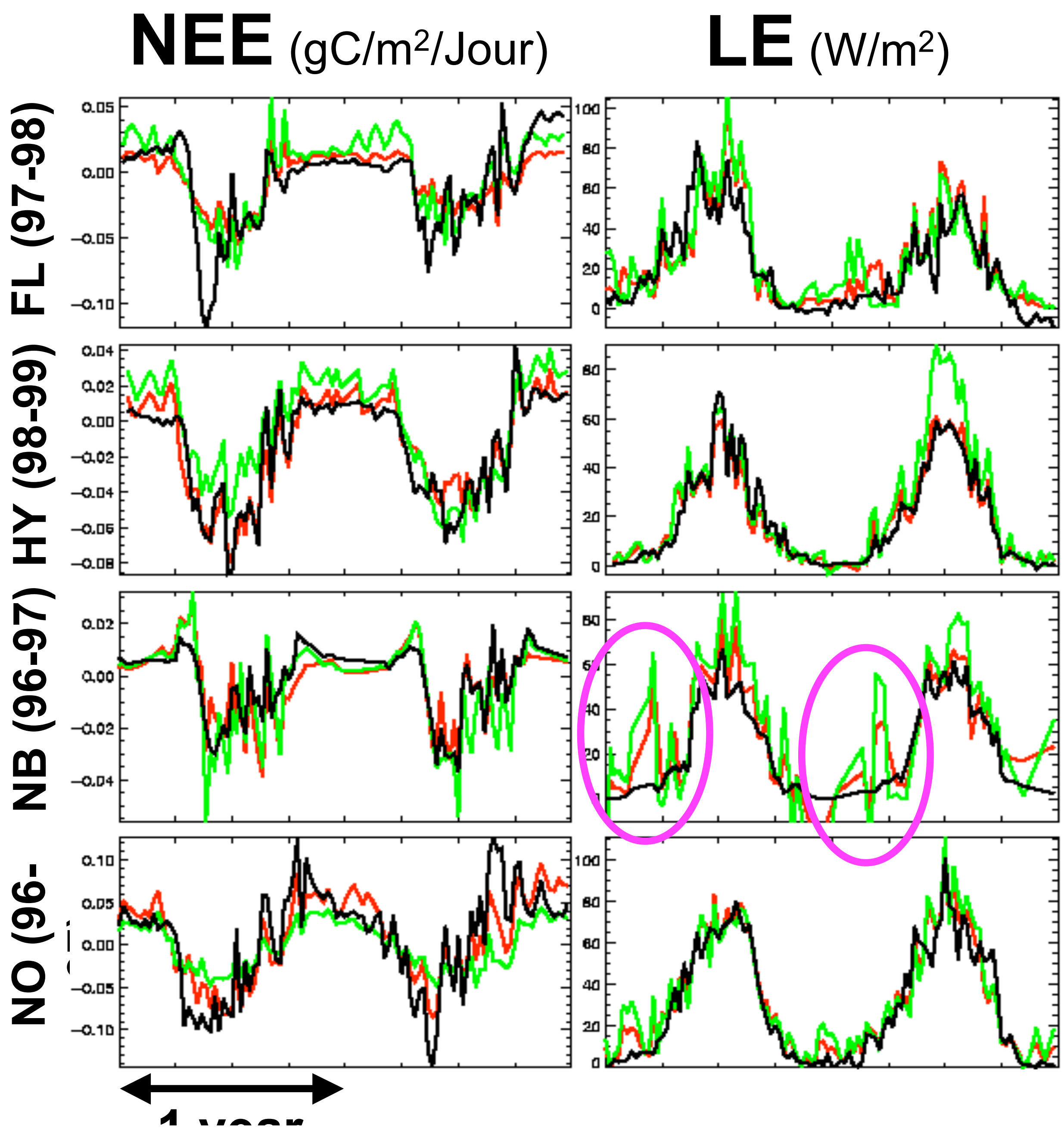
Optimized model

Observations

Delay between model and observed late afternoon build-up

Overestimation of the sensible heat flux during the night

Boreal conifers



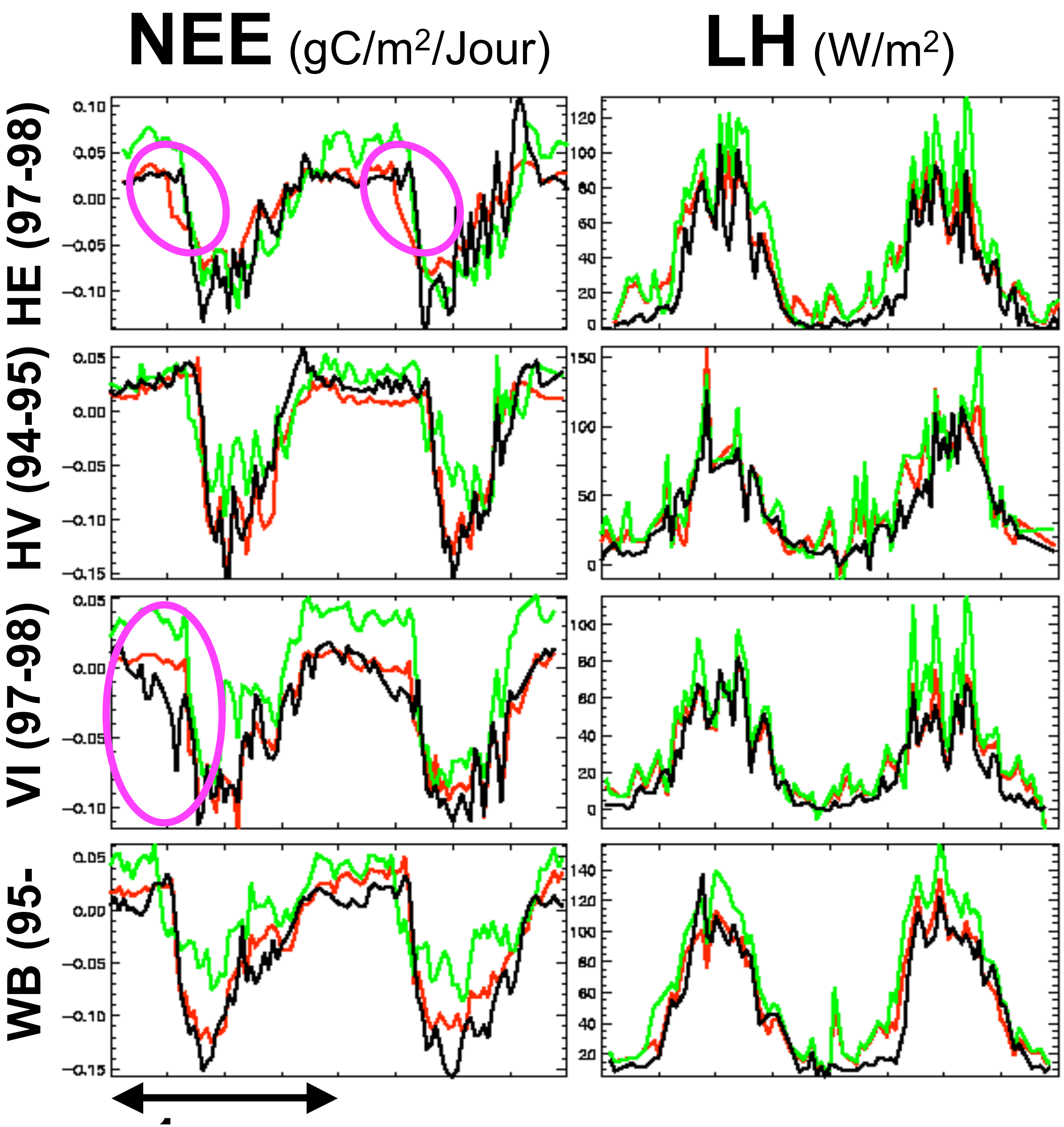
a priori model

Optimized model

Observations

Variability caused by snow Surface Energy Budget calculation

Deciduous : seasonal cycle



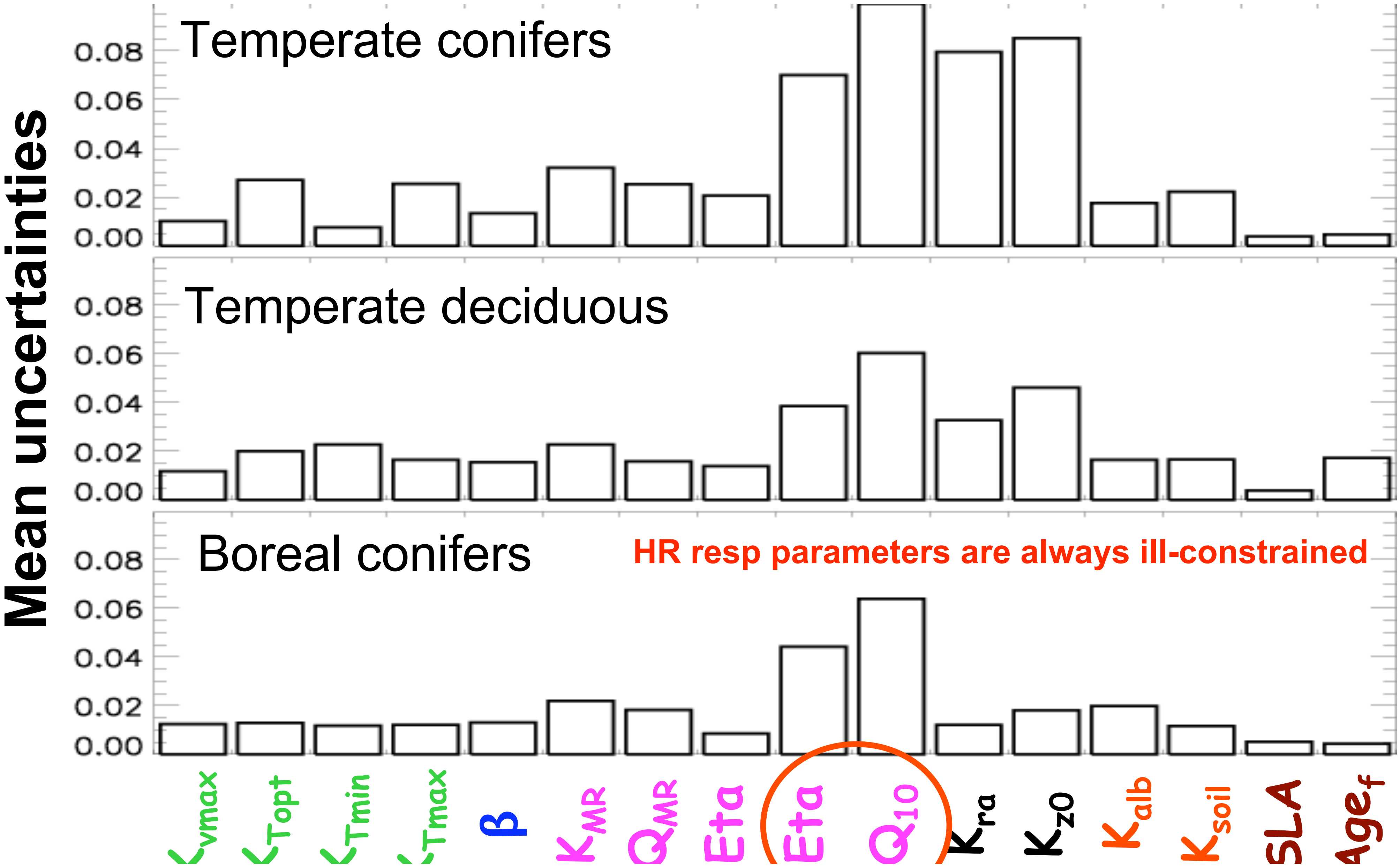
a priori model

Optimized model

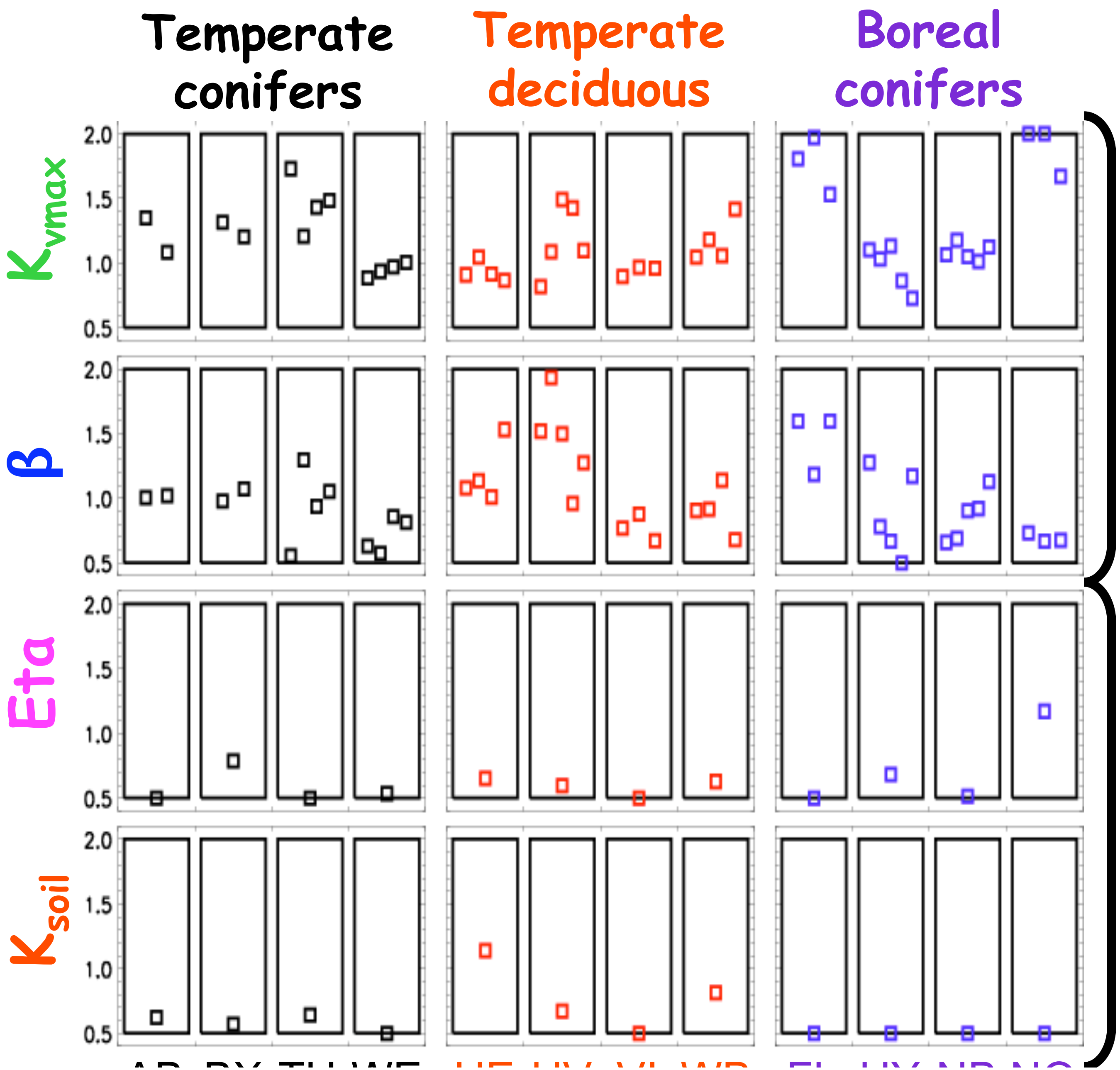
Observations

Onset of the growing season misfit after optimization at Hesse and Vielsam

Parameter uncertainties reduction



Interannual variability : Biotic or climatic factors



Parameters optimized every year

Optimized values differ between

1) years of a same site -> biotic controls

2) sites for the same PFT -> PFT definition, nitrogen status, missing processes

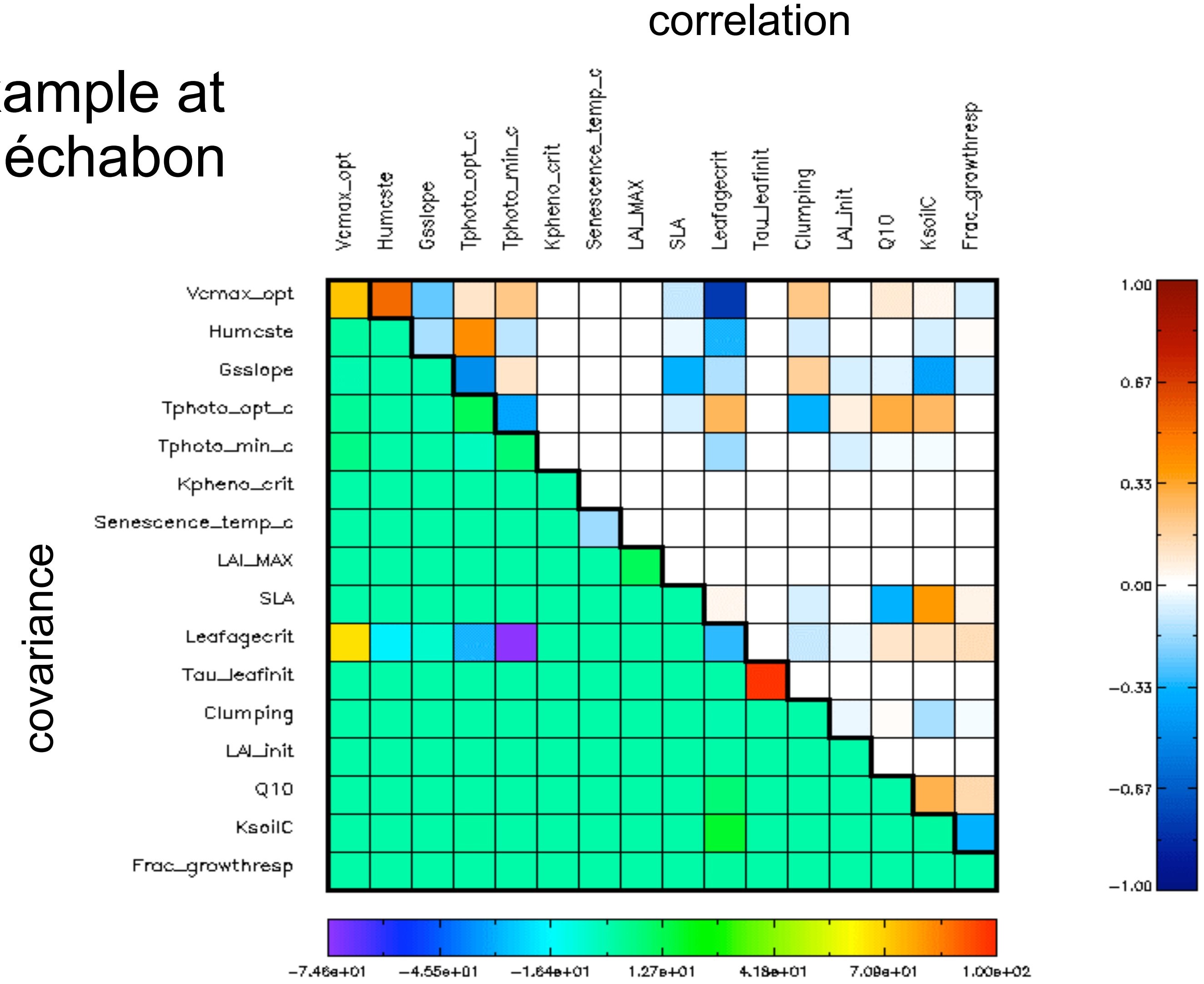
Constant parameters :

Optimized values differ between sites

-> site history, soil physics

Posterior error correlation matrix of parameters

Example at Puéchabon



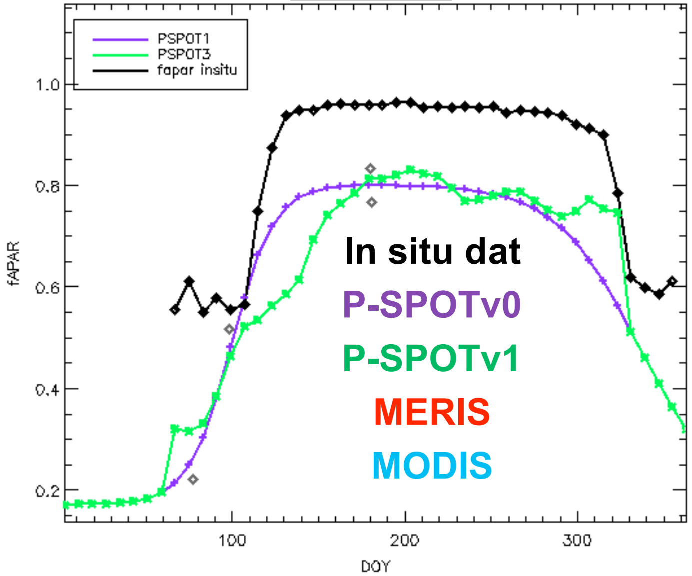
Correlation btw biophysical and phenological parameters (e.g. Vcmax opt with leaf critical age)

Key information on equifinality & parameters correlation

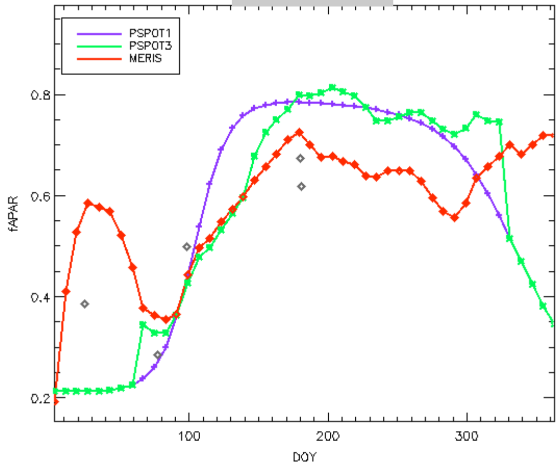
2 Optimization using eddy-flux and satellite / in situ Fapar observations

Satellite & in-situ fapar at Fontainebleau

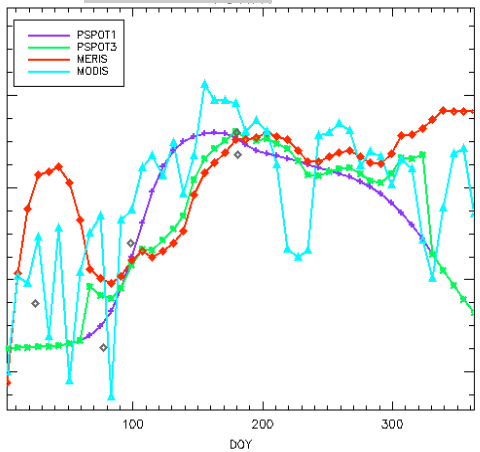
40 m



1 km



10 km



Deciduous oak forest

Eddy-flux measurements

- gap-filled half-hourly measurements (LE, H, NEE)
- year 2006

fAPAR measurements

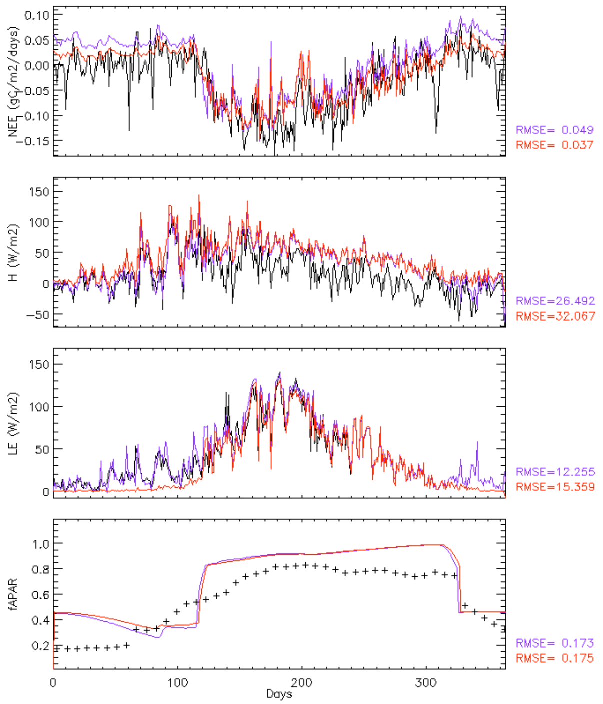
- ✓ SPOT- 40m + temporal interpolation
  V0 = with double-sigmoid model
  v1 = with MERIS seasonality
- ✓ MERIS - 1km
- ✓ IN-SITU = truth

MERIS, MODIS not usable directly

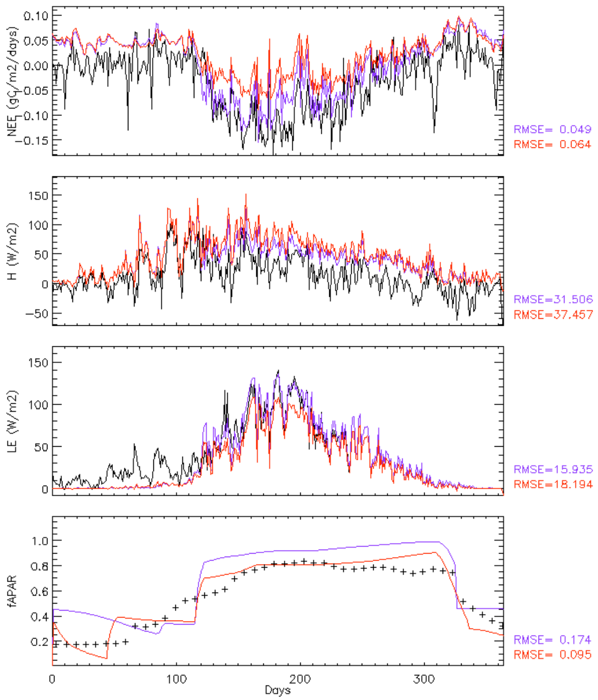
Land cover heterogeneity
Cloud cover
High sun angle in winter

Eddy + satellite fapar assimilation

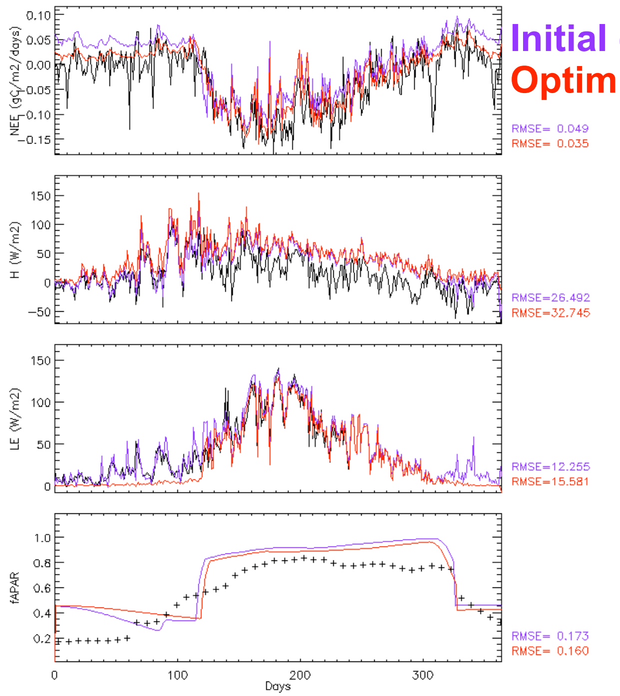
Eddy only



fAPAR only



Eddy + fAPAR



Initial (prio
Optimized

ORCHIDEE simulation set-up

- 80% Temperate Broadleaf 20% C3-Grass
- local meteorology (30' time step)
- SS-EQ spinup of soil C pools

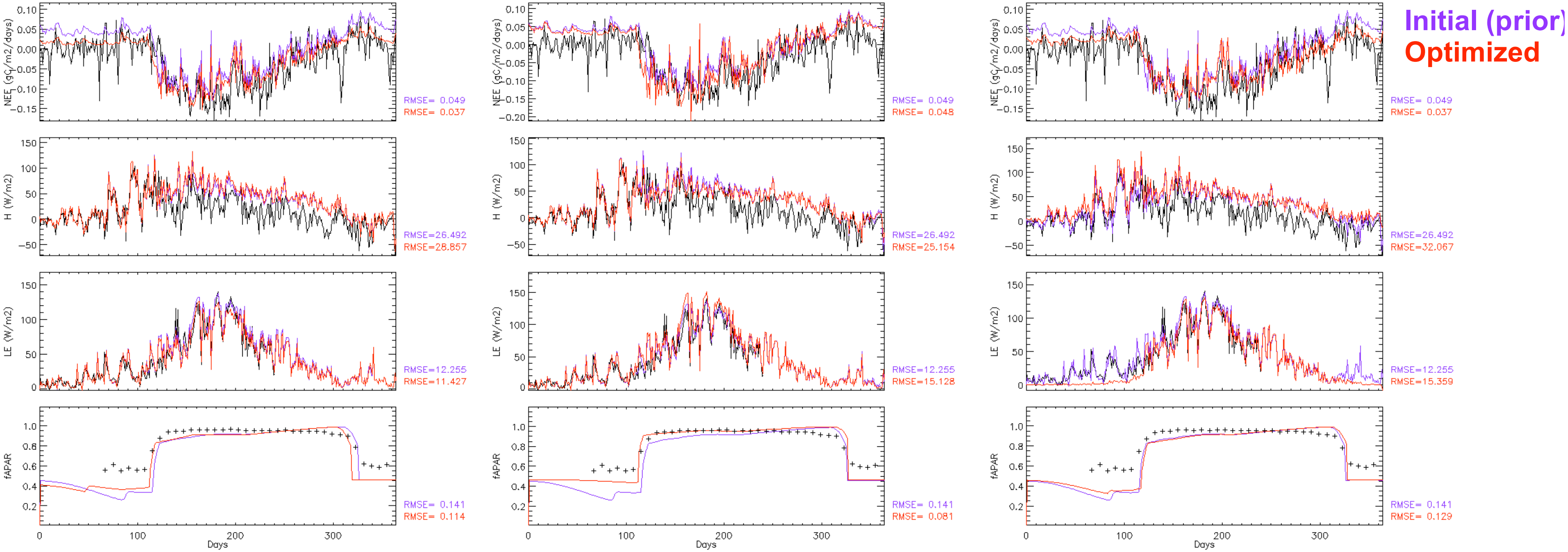
The prior is already quite good except for winter respiration -> SS-EQ spin-up

Early season fapar increases fast and one month later than satellite

Use of satellite fapar degrades flux simulation

Eddy + in-situ fapar assimilation

Eddy only | **fAPAR only** | **Fluxnet + in situ fAPAR**



In situ fapar is consistent with eddy data

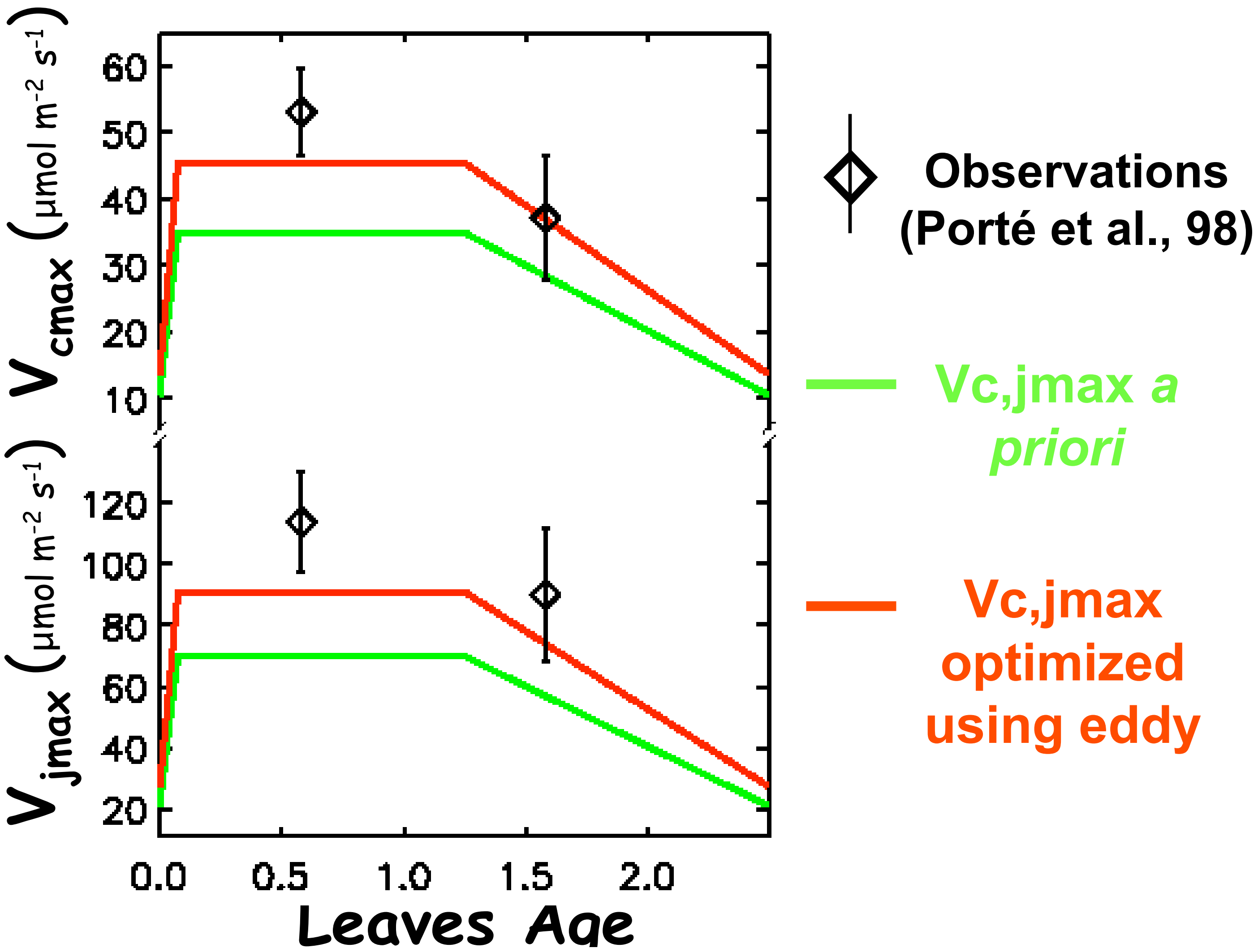
Assimilation of in situ fapar brings a real improvement to flux simulation RMSE is cut by 2)

Conclusion

- Need to separate time-scales in cost function for better control of optimized processes
- Optimized ORCHIDEE simulates well seasonal flux variability
- Diurnal cycle bias -> structural model deficiencies in late afternoon NEE & night-time SH
- Interannual variability (IAV) suggests non-constancy of parameters $V_{cmaxopt}$ and conductance -> Climatic drivers + rigid biophysical parameters cannot explain IAV D. Richardson :-)
- Assimilation of satellite fAPAR created inconsistency with eddy data (wrong timing fAPAR increase) -> land-cover variability / temporal data availability lead to a too-smooth increase of satellite fAPAR
- We learned on deficiencies of the model

Experimental cross Validation

Dependency of the carboxylation rates *wrt* leaves age



3. Tropical forests flux seasonality optimization

Amazon forest greenup during dry periods

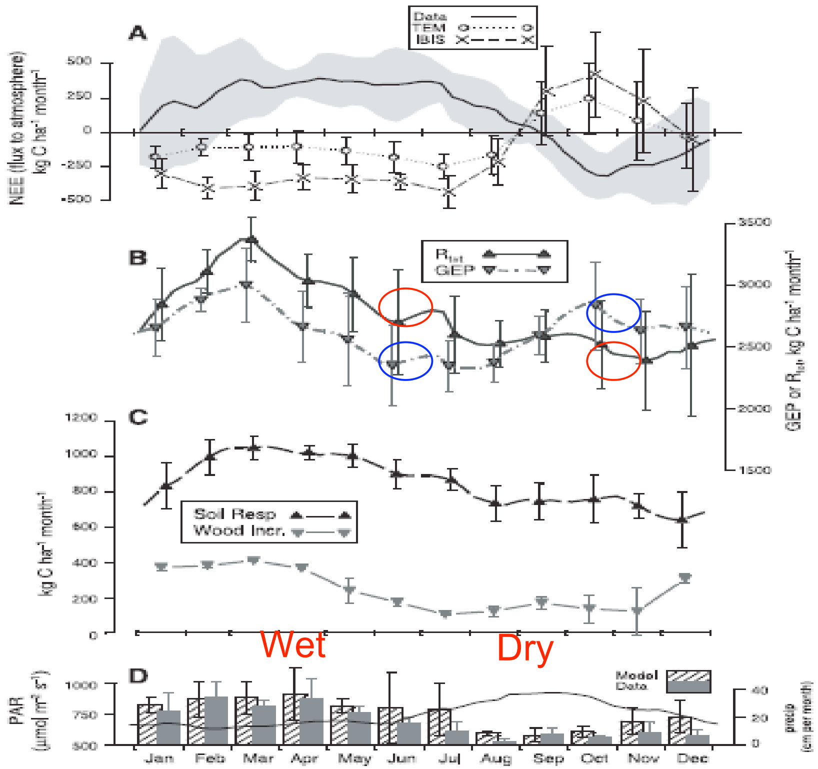
Hypothesis :

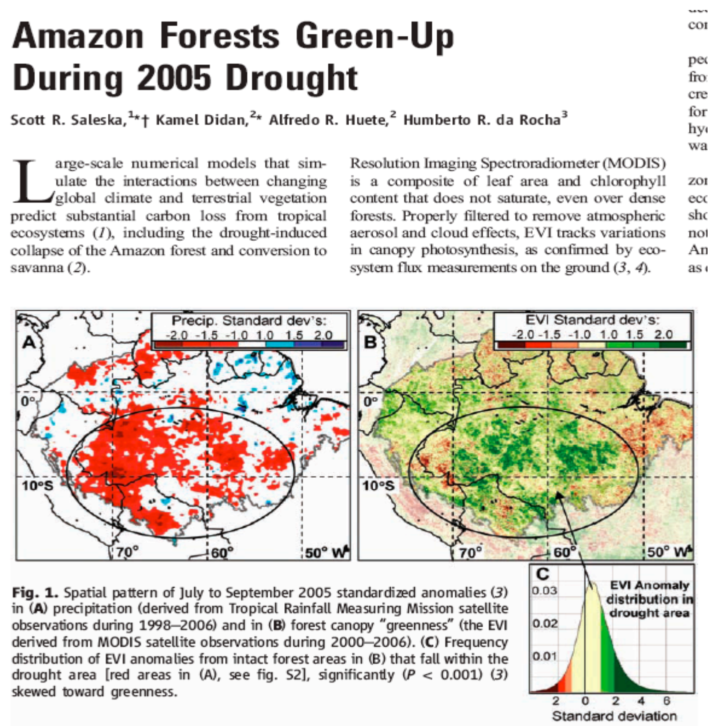
Eddy data indicate increased uptake during the dry season

This response varies among sites

Satellite data -> Amazon-wide forest greenup during dry season

Can we optimize physiological parameters to reproduce this process ?





Amazon Forests Green-Up During 2005 Drought

Scott R. Saleska,[1*†] Kamel Didan,[2*] Alfredo R. Huete,[2] Humberto R. da Rocha[3]

Large-scale numerical models that simulate the interactions between changing global climate and terrestrial vegetation predict substantial carbon loss from tropical ecosystems (*1*), including the drought-induced collapse of the Amazon forest and conversion to savanna (*2*).

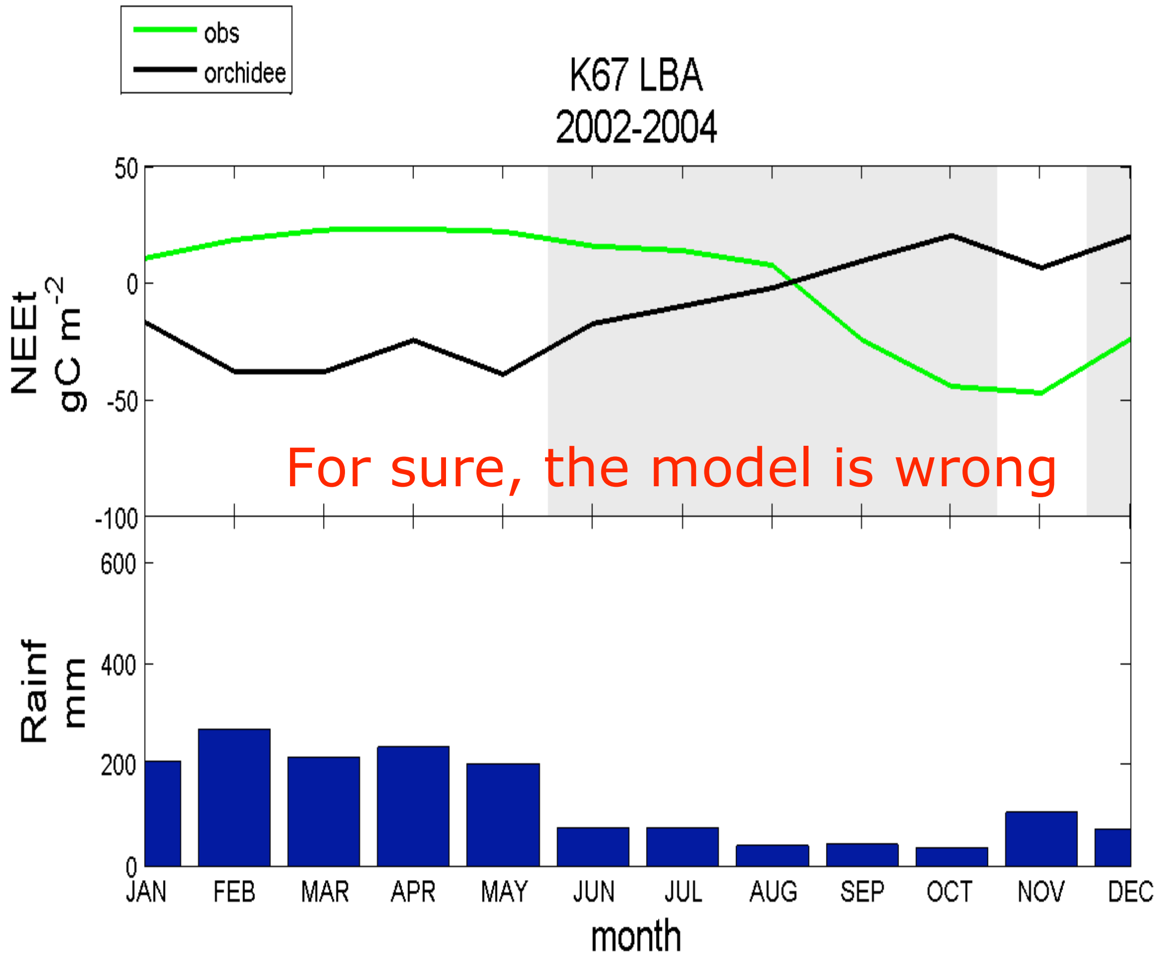
Resolution Imaging Spectroradiometer (MODIS) is a composite of leaf area and chlorophyll content that does not saturate, even over dense forests. Properly filtered to remove atmospheric aerosol and cloud effects, EVI tracks variations in canopy photosynthesis, as confirmed by ecosystem flux measurements on the ground (*3*, *4*).

Fig. 1. Spatial pattern of July to September 2005 standardized anomalies (*3*) in (**A**) precipitation (derived from Tropical Rainfall Measuring Mission satellite observations during 1998–2006) and in (**B**) forest canopy "greenness" (the EVI derived from MODIS satellite observations during 2000–2006). (**C**) Frequency distribution of EVI anomalies from intact forest areas in (B) that fall within the drought area [red areas in (A), see fig. S2], significantly ($P < 0.001$) (*3*) skewed toward greenness.

Example of NEE simulation at km67 (Steve Wofsy's site)

Possible explanations

- Deep rooting, deep soil columns with high water storage.
- Hydraulic redistribution
- More light during dry season
- More efficient leaves
- More leaves
- Respiration collapse in dry upper soils



This problem has stimulated model developments :

- V_{cmax} and phenology (Ben Poulter et al. with LPJ)

- Soil hydrology, root hydraulic uplift, respiration (Baker et al. with SIB-3)

Model optimization strategy using NEE, LE and H daily fluxes

$$J(x) = \frac{1}{2}\left[(y - H(x))^t R^{-1} (y - H(x)) + (x - x_b)^t P_b^{-1} (x - x_b)\right]$$

- Mismatch between (1) model and daily observed fluxes and (2) a priori and optimised parameters
- Covariance matrices contain a priori uncertainties on parameters and fluxes including correlations

Eddy data (NEE, LE, H)

Manaus (Km 34), Brazil
Santarém (Km 67), Brazil
Santarém (Km 83), Brazil
Reserve Jaru, Brazil
Guyaflux, French Guyana

Optimised parameters:

Vcmax opt

Fstress

Q10

Soil Depth

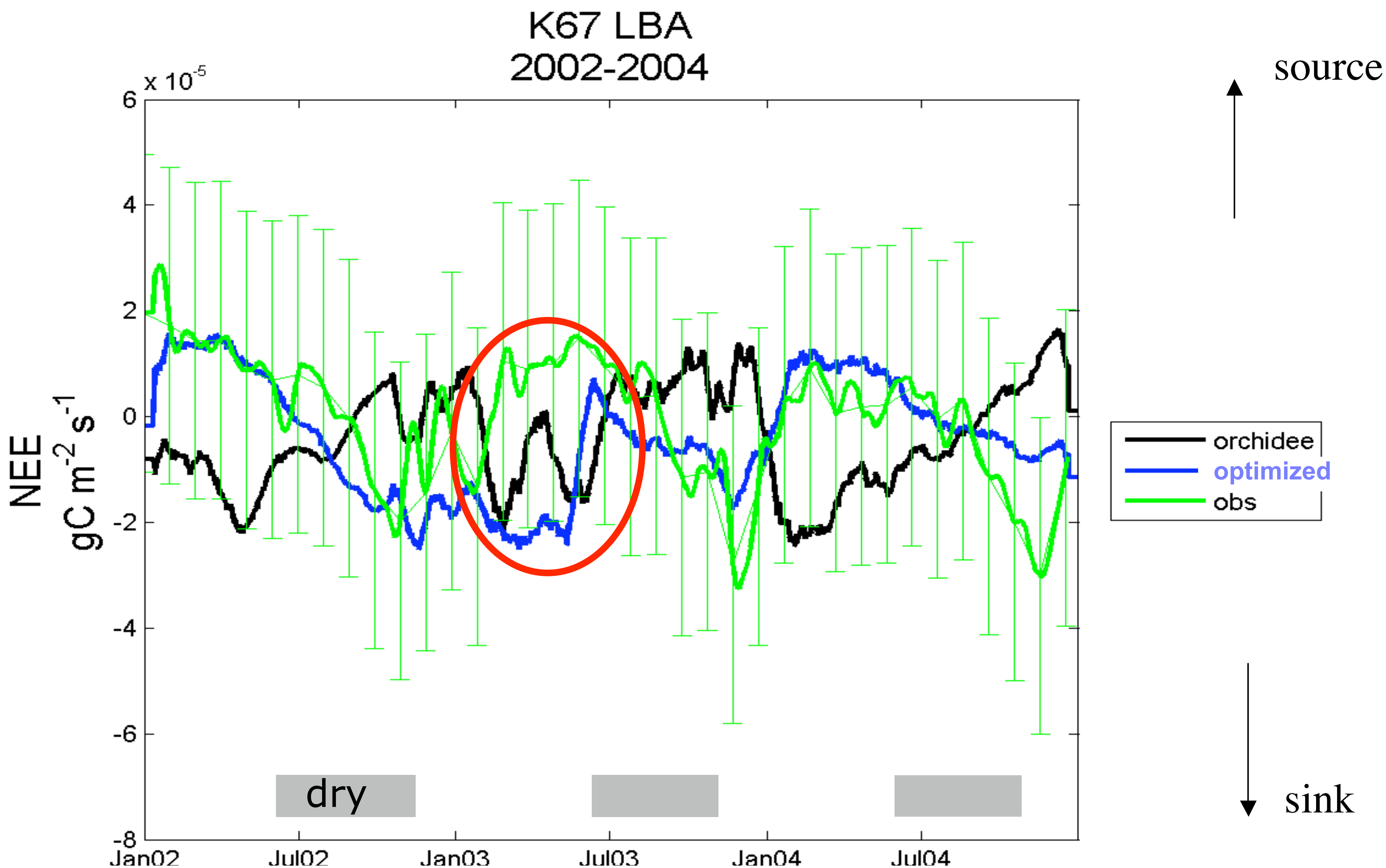
Conductance slope

Albedo

SoilC 'eta' multiplier

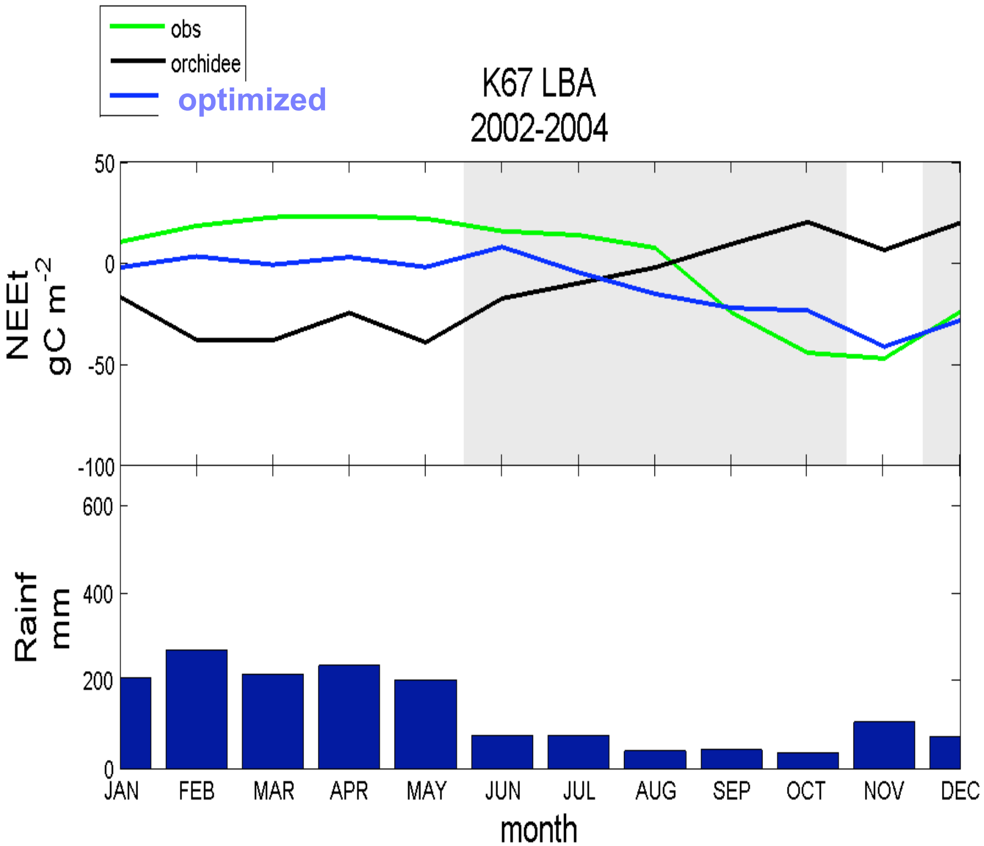
Results : fit to NEE observations

Dry season uptake can be reproduced ; residual misfit during 'rewettening'

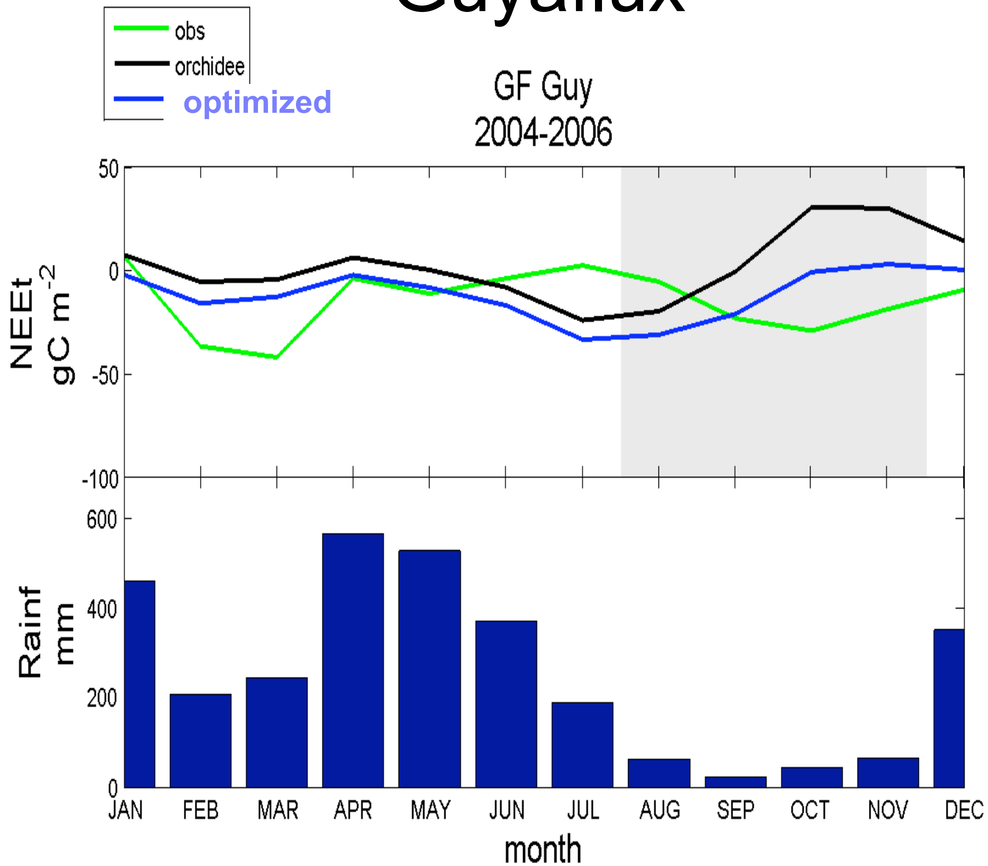


Results : fit to NEE observations

Km 67



Guyaflux



Model NEE seasonal phase is reversed

Most important parameters changes

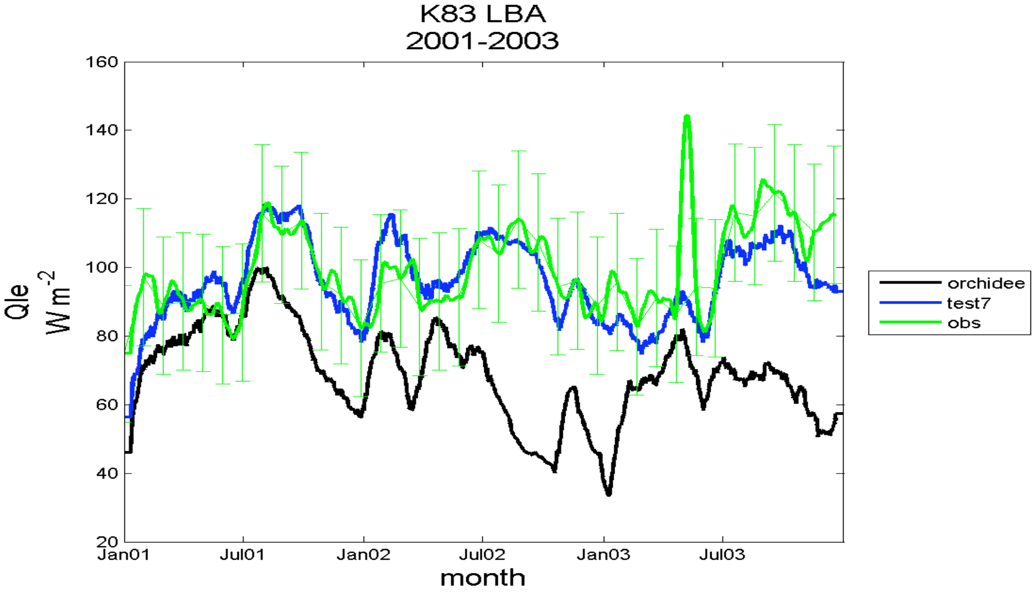
Q1O (decrease to ≈ 1)

Fstress (relieved)

Model NEE seasonal phase is NOT Changed

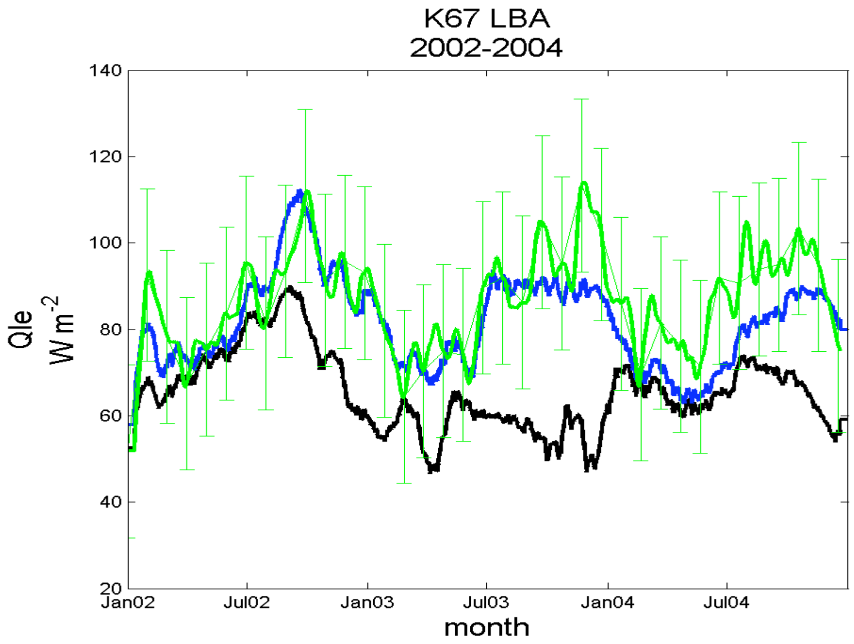
But amplitude is reduced

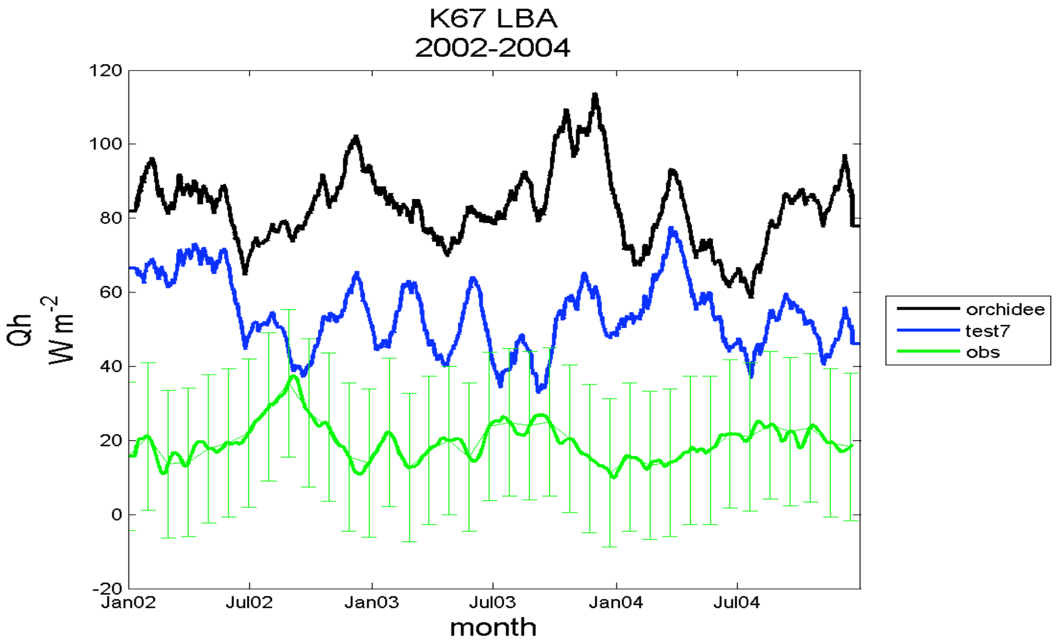
Results : fit to sensible & latent flux



- Latent heat flux is well fitted after optimization

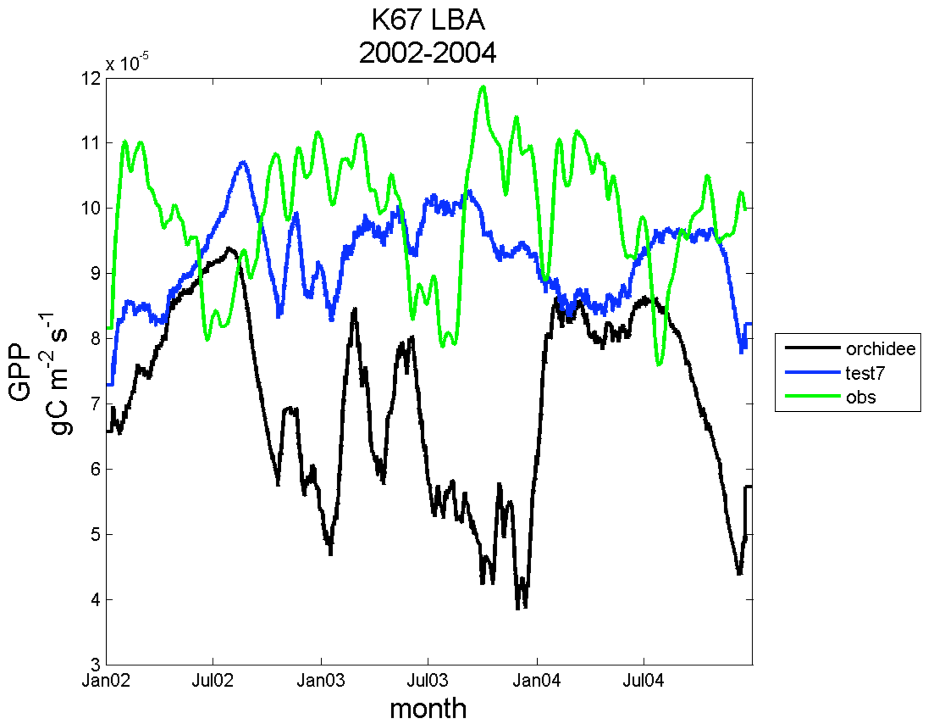
- Sensible heat flux under-estimated (energy balance closure problem in data)





Results : separating of gross fluxes by optimization

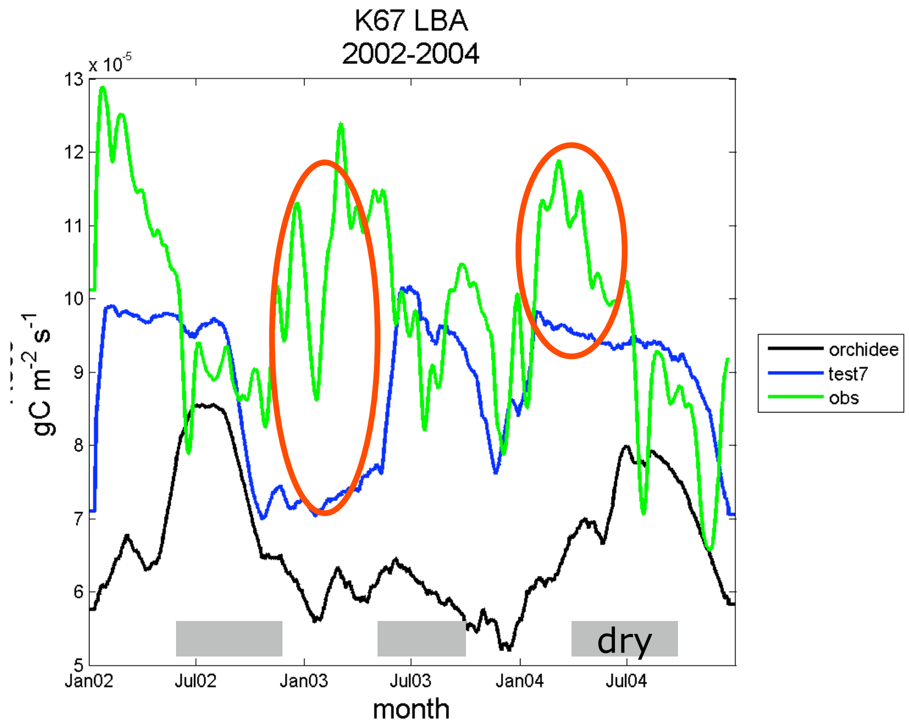
GPP at km 67



Relatively good agreement (given large error on empirical partitionning method)

GPP maxima during dry periods

R_{eco} at km 67



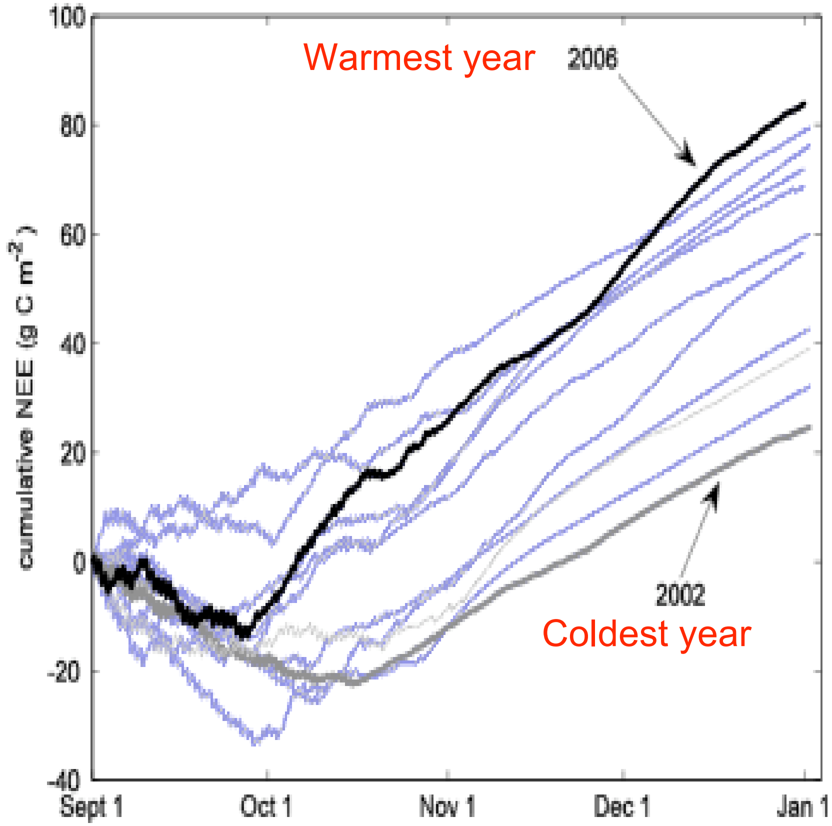
Deficiency to reproduce Reco response to dry / wet cycles

Fast increase of Reco by re-wetting

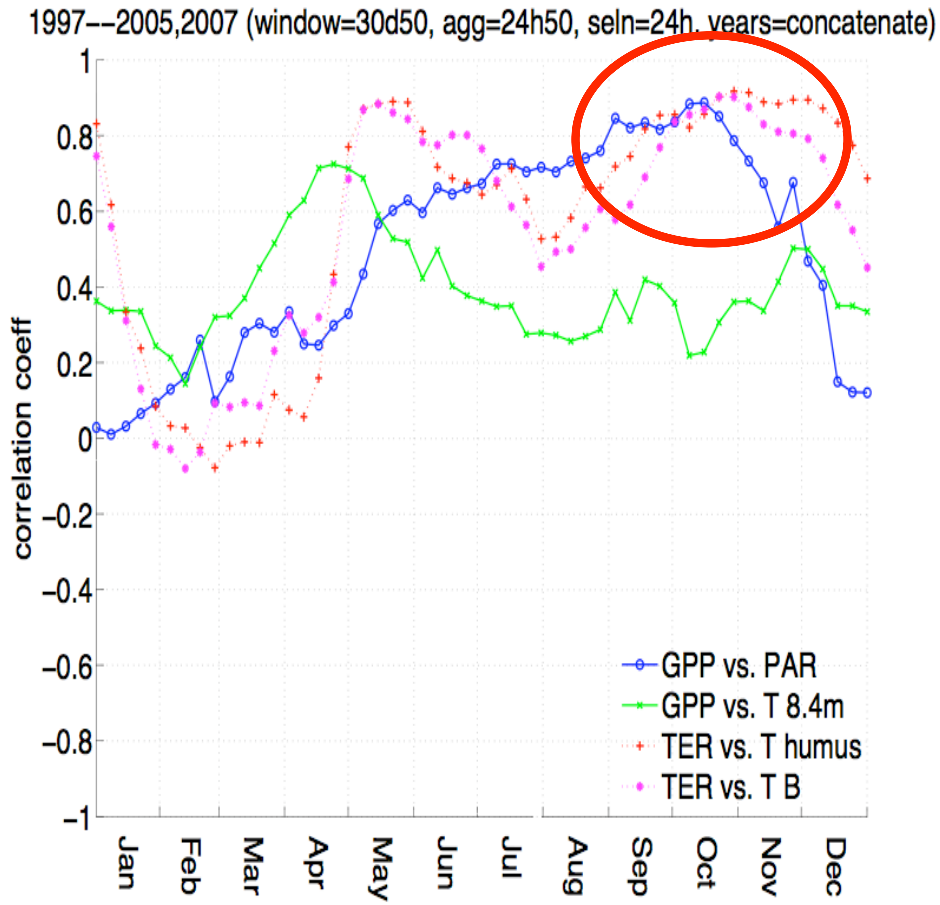
4. Calibrating the modelled response of fluxes to climate

Case study : Hyytiala scott's pine forest in Finland

Hypothesis :
Autumn C balance observed to be driven by temperature
How well can this response be reproduced by a model ?

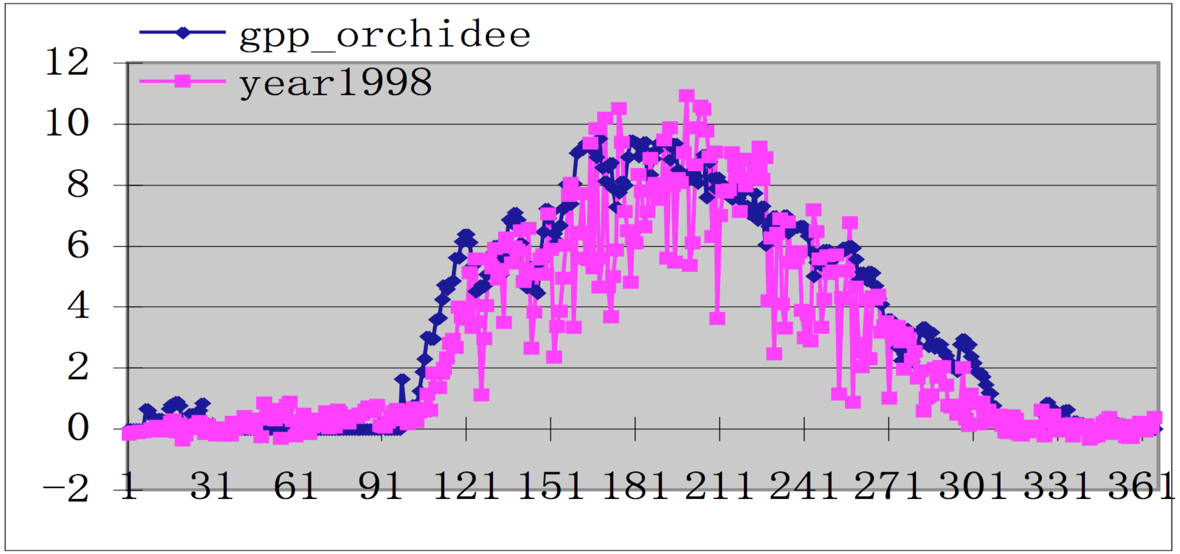


NEE autumn variance driven by temperature, also determines annual NEE variance



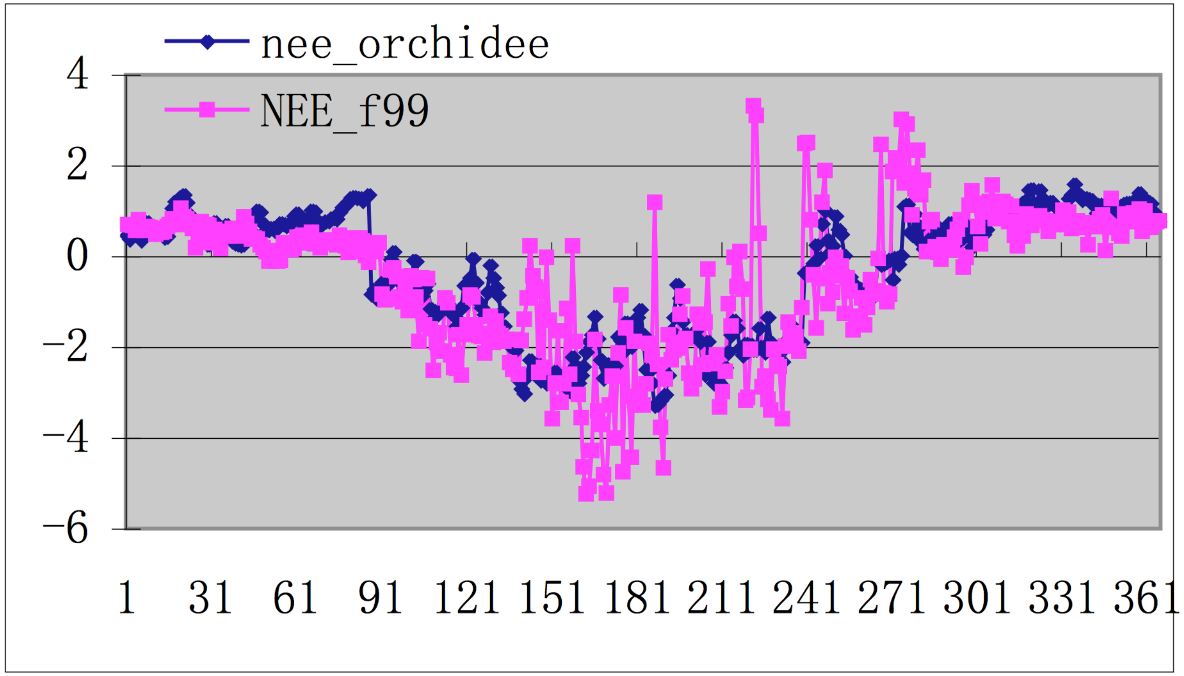
High positive correlation over 10 years
Autumn GPP vs. PAR & TER vs. T

Model seasonal performances look good at first glance



GPP

Note : not enough variability because of weather generator was used to produce hourly forcing

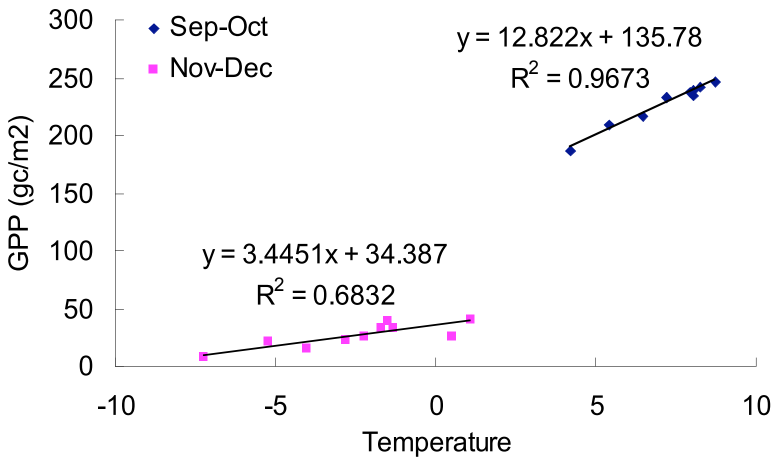


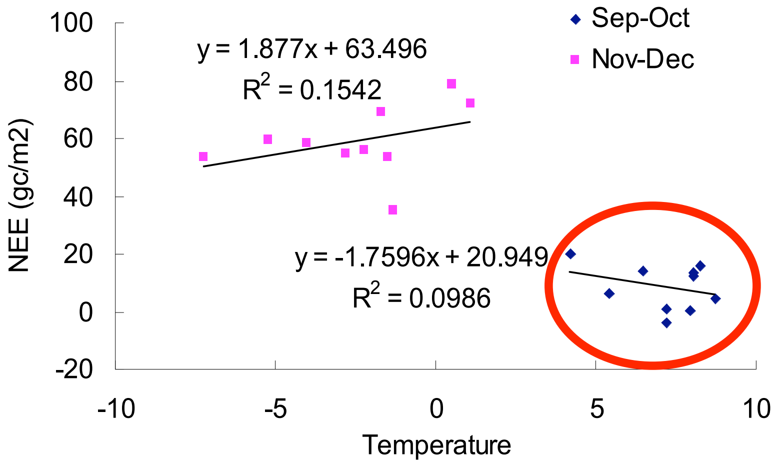
NEE

But how realistic is the modelled sensitivity to T ?

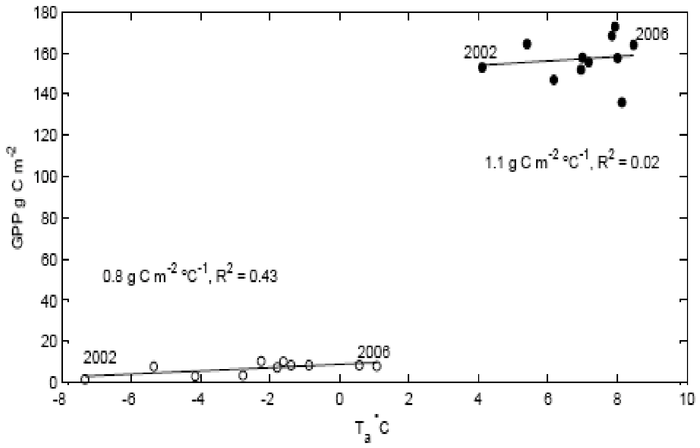
Modelled and observed flux-temperature regressions

Model

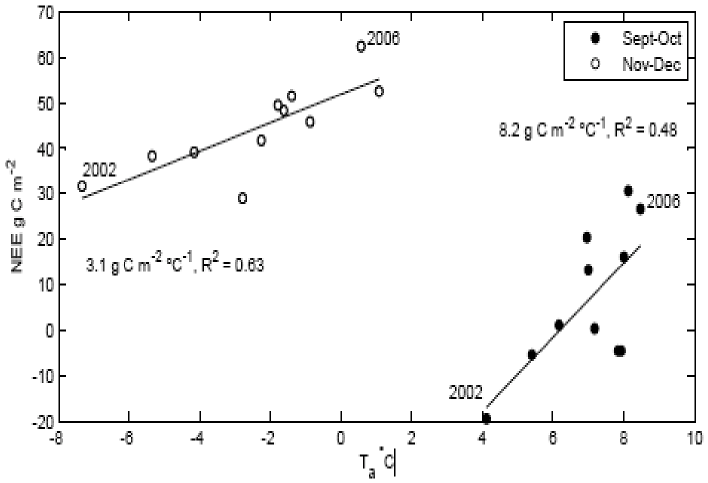




Observations



GPP



NEE

Wrong sign for autumn NEE response to T
- soil C is not vertically discretised
- too strong response of GPP (senescent needles)

Conclusions

- Finland autumn temperature : a good fit of optimized fluxes to observations can masquerade model structural deficiencies
- Amazon green-up : optimization can produce greater GPP during dry season (but parameter equifinality)
- Recomandations: diagnose flux sensitivities to climate from the data and use these to test models for these sensitivities

Other things (important)

- An important validation activity is developping for global models used for coupled climate-carbon prediction (such as JULES, JS-BACH, ORCHIDEE)
- Need to define new integrated metrics to assess model performances using eddy data
  - Sensitivities
  - Seasonal, interannual variability
- This group is ideally placed to write benchmark paper for defining this metrics
- Maybe should a task force be formed about this ?